# Dynamics of Coupled Contaminant and Microbial Transport in Heterogeneous Media

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## Statement of the Problem

OEM subsurface remediation involves contaminant mixtures in physically, chemically, and microbiologically heterogeneous environments:

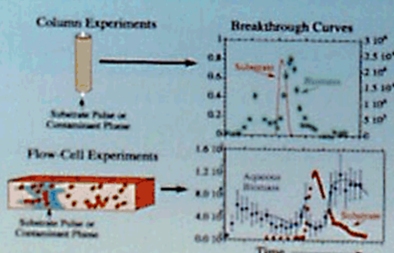
- Subsurface physical and chemical heterogeneities affect the transient spatial distribution of contaminants and microorganisms and therefore influence subsurface manipulation strategies
- Prediction and control of in situ bioremediation requires quantitative linkage of basic processes controlling degradation and microbial transport with dynamic nutrient flux and growth conditions in natural heterogeneous systems.
- We do not understand the transport behavior of anaerobes.

Bacteria can move during biodegradation, yet biomass is generally treated as a fixed phase in models.

If we understood transport behavior we could:

- develop realistic predictive tools
- enhance bioremediation to take advantage of the transport behavior of bacteria
- assess staged remediation strategies for dealing sequentially with mixed contaminants

## Evidence that Bacteria Move in Response to a Contaminant Plume:




## Under Contaminant (nutrient-rich) Conditions the Aqueous proportion of Biomass Increases

- Harvey, R. W., R. L. Smith, and L. George, 1984. *Applied and Environmental Microbiology* 48(6):1197-1202.
  Aqueous biomass increased by an order of magnitude in a contaminated portion of the aquifer while the biomass on the sediments remained the same.
- Godsy, E. M., D. F. Goerlitz, and D. Grbic-Galic, 1992. *Ground Water* 30(2):232-242.
  Although 90% of the biomass was attached in a creosote-contaminated aquifer, 49% of the creosote-degrading methanogens were in the aqueous phase.
- DOE Savannah River Demonstration, 1993.
  A five order of magnitude increase in methanotrophs occurred in the aqueous phase with the addition of nutrients.
- Murphy, E.M., T.R. Ginn, et al., 1997. *Water Resources Research* 33(5):1087-1103.

## Example of How Dynamic Partitioning of Bacteria can Effect the Degradation of a Contaminant Plume

Kinetic Attachment/Detachment: A forward (attachment) and reverse (detachment) rate kinetic determines the relative concentrations of bacteria in the aqueous and solid phases.

$$\phi\frac{\partial C_{Lm}}{\partial t}+\nabla\cdot(C_{Lm}V) = \nabla\cdot[D\nabla C_{Lm}] + \mu_L C_{Lm}\left[\frac{C_p}{K_p+C_p}\right] - K_{Li}C_{Lm} + K_{iL}C_{Li}$$

$$\frac{\partial C_{Li}}{\partial t} = \mu_L C_{Li}\left[\frac{C_p}{K_p+C_p}\right] + K_{Li}C_{Lm} - K_{iL}C_{Li}$$

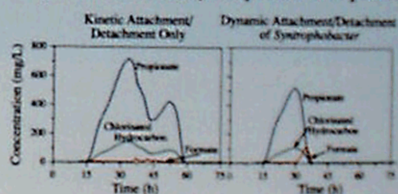
Dynamic Attachment/Detachment: the forward and reverse rate kinetic varies dynamically with growth.

$$\phi\frac{\partial C_{Lm}}{\partial t}+\nabla\cdot(C_{Lm}V) = \nabla\cdot[D\nabla C_{Lm}] + \mu_L C_{Lm}\left[\frac{C_p}{K_p+C_p}\right] - K_{Li}C_{Lm}\left(1-\left[\frac{C_p}{K_p+C_p}\right]\right)^{*} + K_{iL}C_{Li}$$

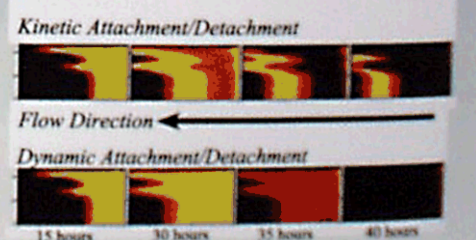
$$\frac{\partial C_{Li}}{\partial t} = \mu_L C_{Li}\left[\frac{C_p}{K_p+C_p}\right] + K_{Li}C_{Lm}\left(1-\left[\frac{C_p}{K_p+C_p}\right]\right)^{*} - K_{iL}C_{Li}$$

In this simulation we compare the dechlorination of PCE when *D. tiedjei* and *Syntrophobacter* attachment/detachment is:

- kinetic only
- *D. tiedjei* kinetic while *Syntrophobacter* dynamic



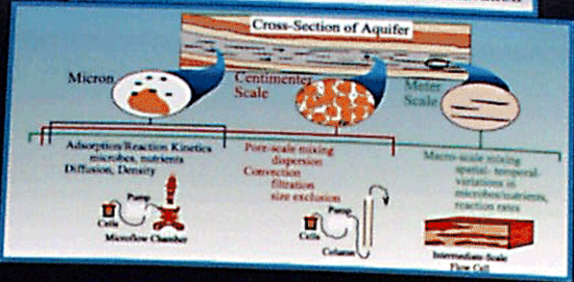

## Cross Section of Flow Cell Showing Transient Dechlorination of PCE Plume



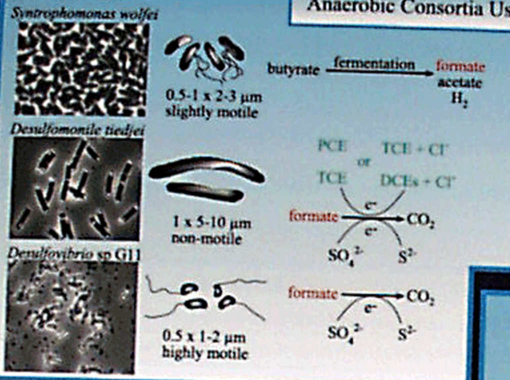

## Simulation Results

58% more of the contaminant is degraded when *Syntrophobacter* undergoes dynamic attachment/detachment. This is due to enhanced aqueous partitioning of *Syntrophobacter* which results in an increasing population of this propionate degrading organism as the contaminant moves along the groundwater flow path.

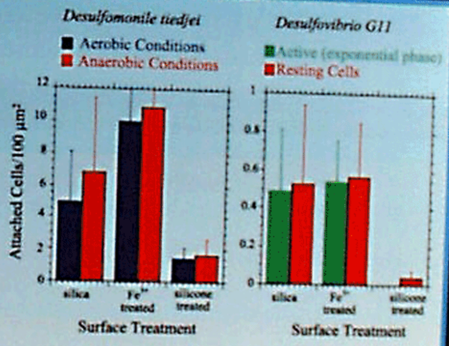
## Research Approach Based on Scales of Observation



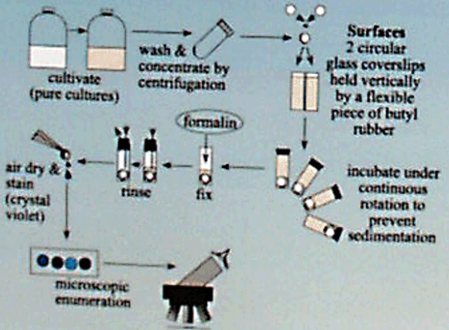

## Anaerobic Consortia Used in Experiments

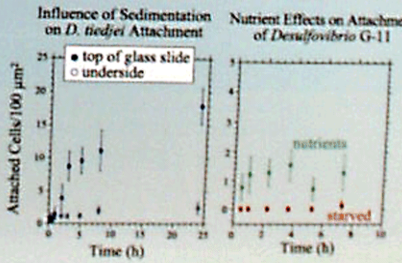



| Anaerobe | Function/Reason for Selection |
|---|---|
| *Desulfomonile tiedjei* | reductive dehalogenation of chlorinated hydrocarbons |
| *Syntrophomonas wolfei* | butyrate-degrading, produces $H_2$, acetate, formate for *D. tiedjei* |
| *Desulfovibrio G-11* | competes with *D. tiedjei* for sulfate as e⁻ acceptor & formate |
| *Methanospirillum hungateii* | competes with *D. tiedjei* for formate, naturally fluorescent |




## Micron-Scale Experiments of Bacterial Adhesion Processes




### Results of Micron Scale Experiments:

- Mineral surface charge has variable effects on anaerobe adhesion within the consortia
- Sedimentation significantly affects the adhesion of *D. tiedjei* and *D. tiedjei* adhesion is irreversible
- *Desulfovibrio* G11 attachment greater in the presence of nutrients.
- *S. wolfei* showed strong adhesion to surfaces, but only in the presence of substrate (*S. wolfei* grows on crotonate in pure cultures and butyrate in consortia).